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The development of environmental load evaluation system of a standard Korean apartment house

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ABSTRACT

The purpose of this study is to develop a simple method to assess the amount of carbon dioxide (CO_2) emitted during the production of construction materials used in the construction of a standard Korean apartment house. This study is part of a wider effort to develop a system for evaluating the environmental load of construction during architectural planning and basic design phases.

We formulated models of a standard Korean apartment house and a super high-rise apartment house, based on five reference floor plans for "green homes" provided by the Korean government. We identified major construction materials that account for over 80% of the CO_2 emission that occurs during construction and built a database to evaluate the environmental loads of these materials according to house types described in terms of area, block type, combination of living units, or number of floors. We used the information in this database to develop technology to assess the amounts of CO_2 that are emitted during the production of construction materials used to build residential apartment houses in Korea.

Contents

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1. Introduction

It is probable that a post-Kyoto protocol, or convention on climate change that applies to the widest scope of society will need to be formulated in order to combat the accelerating pace of global warming. Numerous efforts have already been made to reduce greenhouse gases according to the Kyoto Protocol adopted in 1997 by the United Nations Framework Convention on Climate Change (UNFCCC). The most pressing issue of the post-Kyoto regime, however, is that the countries most often blamed for high greenhouse gas emissions were excluded from the group of Annex I countries. As a result, serious attempts to adopt a farther-reaching global convention on climate change, including both industrialized and developing countries after 2013, have been made [1,2].

Since an international bond of sympathy has developed and the post-Kyoto regime has approached the Korean government presenting both opportunities and threats, the Korean business sector has started to make efforts to respond to the problem of climate change. For example, one large company in Korea recently announced a "Green Management" scheme, voluntarily set a goal of reducing greenhouse gases, and proclaimed that it will make a large-scale investment in facilities to reduce carbon and develop environment-friendly technologies. The amount of greenhouse gas emission in Korea, however, has continued to increase, and if Korea fails to address these problems it is likely that Korean businesses will lose opportunities to enhance Korea's export strength and to create new growth engines [3–5].

Until recently, Korean construction companies have placed little priority on decreasing environmental load (CO_2). However, environmental concerns have led the Korean construction community to develop environment-friendly element technologies aimed at reducing carbon dioxide (CO_2) emissions that occur during the construction of new buildings. Such technologies must be accompanied by the development of a system for evaluating the environmental load (CO_2) of newly-constructed buildings, but few active efforts to develop such environmental load evaluation programs have been made [6–9].

We developed a method to evaluate the lifetime environmental load of a newly-constructed building by using a minimum amount of data derived only during the architectural planning and basic design stages, that does not require data regarding the actual construction of the building or calculation of energy consumption. We then identified the main construction materials responsible for CO_2 emission during the construction of apartment houses, and tested our new method, which easily evaluated the amount of CO_2 emitted during the production of materials used for construction [10,11].

2. Standard apartment house

2.1. Selection of standard apartment house

A standard apartment house consists of certain combinations of living units, number of floors, structure and strength. Five standard apartment house models were described in the Guideline for Evaluating Design and Performance of Green Houses subject to the Criteria to Build Green Houses and their Performance, announced in October 2009 by the Ministry of Land Transport and Maritime Affairs of Korea. The "standard apartment house" referred to in this study is a reference house designed for the evaluation of environmental load (CO_2). Based on five floor plans designated as "Green Home" reference plans by the Korean government, we designated floor plans for apartment houses of 15–20 stories as standard apartment house models (hereafter referred to as "general standard apartment houses"), as well as a standard model for a super high-rise (60-story) apartment house (hereafter referred to as "super high-rise standard apartment house") [12,13].

The Guideline for Evaluating Design and Performance of Green Houses uses reference designs for baseline evaluations, and therefore the standard floor plans used in this study were designed for use in comparisons of energy savings and CO_2 reduction. The Guideline describes typical floor plans (36–125 m^2) for Korean apartment houses, including the areas of their walls, windows, doors, floors, roofs, and other parts.

2.2. General standard apartment house

The general standard apartment houses were selected on the bases of area, combination of living units, number of floors, structure, strength, and other factors. The lettable areas of the apartment houses were divided into five groups by size: 36 m^2, 46 m^2, 59 m^2, 84 m^2, and 125 m^2. The block arrangements of buildings are divided into flat, tower, block, and terrace house types, and of these, the flat and tower types are the most common. The flat type denotes a floor plan that forms a straight line while the tower type describes a floor plan in which the ratio of the short side to the long side is 1:2 or less.

In this study, the living units were arranged in either two-unit or four-unit combinations, because these are the two most prevalent types of block arrangement in Korea. Therefore, the general standard apartments were classified as two-unit combined flat type, four-unit combined flat type, or four-unit combined tower type. Figs. 1 and 2 show the five floor plans, block arrangements, and combinations of living units of the general standard apartment houses considered in this study. Ceiling height was set at 2.9 m for all floor plans after consideration of air supply and ventilation systems. The number of floors was limited to 15- to 20-stories, as these are the most common building heights in Korea. The structures of all buildings incorporated wall column type reinforced concrete, with the strength of the concrete set to 24 MPa for all floors for practical reasons. Table 1 outlines the specifications of the general standard apartment house models considered in this study.

2.3. Super high-rise standard apartment house

A model of a super high-rise standard apartment house was formulated using the criteria of area, combination of living units, number of floors, structure, strength, and other factors. The lettable areas of the super high-rise standard apartment houses were divided into three groups by size: 118 m^2, 121 m^2, and 178 m^2. The areas differed according to floor: the third to the 28th floors incorporated four-unit combinations of 118 m^2 and two-unit combinations of 121 m^2, with six-unit combinations in

Table 1
Constitution of general standard apartment houses.

Constitution	Description
Lettable area	36 m^2, 46 m^2, 59 m^2, 84 m^2, 125 m^2
Block arrangement	Flat type: the floor plan is a straight line. Tower type: the ratio of the short side to the long side of the plan is 1:2 or less.
Combination of living units	Flat type: one combination (two-unit combined flat type) Tower type: two combinations (four-unit combined flat type, four-unit combined tower type)
Height of ceiling	2.9 m: air supply and ventilation systems are taken into account.
Number of floors	15–20 floors
Structure	Wall-column structure of reinforced concrete
Concrete strength	24 MPa for all floors

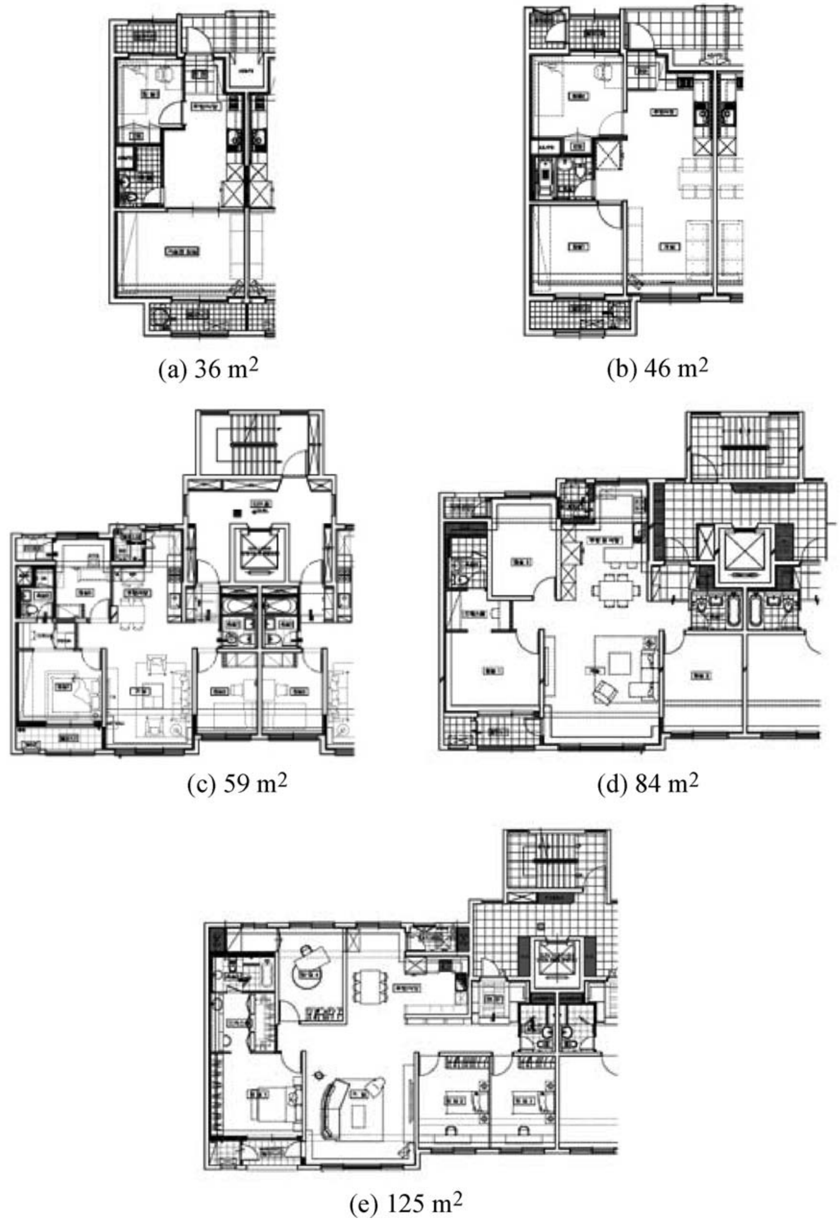


Fig. 1. Five floor plans of general standard apartment houses.

total; the 30th to the 60th floors incorporated four-unit combinations of 178 m^2. Fig. 3 shows the block arrangements and combinations of living units of the super high-rise standard apartment houses considered in this study.

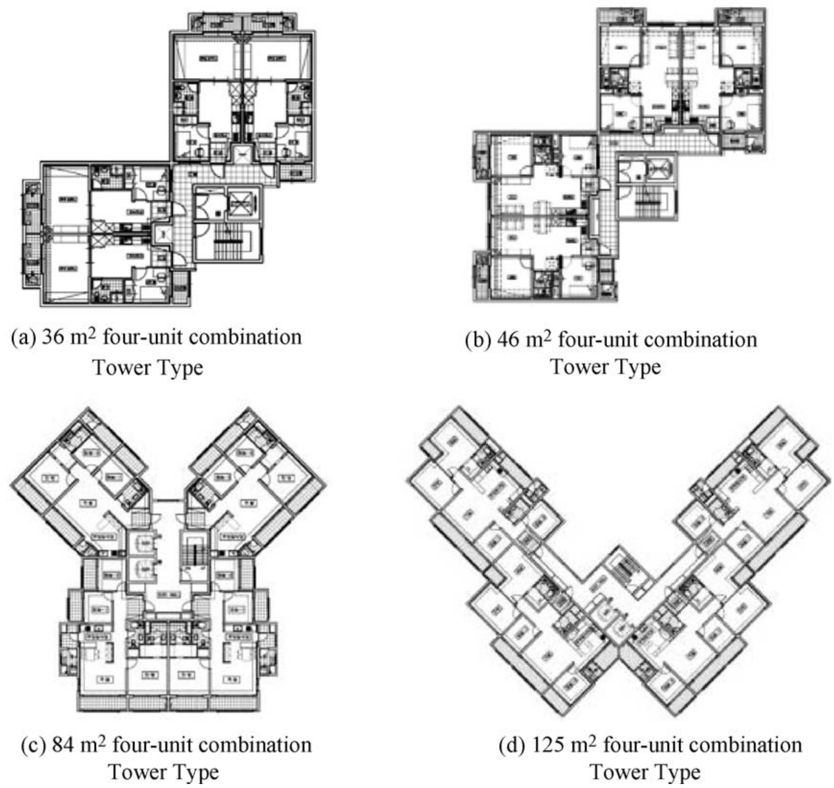
The tower type block arrangement was used for the super high-rise standard apartment houses considered in this study because it is the most common arrangement found in tall Korean buildings. As for the combination of living units, two floor plans were combined for the third to 28th floors, while one floor plan was used for the 30th to 60th floors. The ceiling height was set at 2.9 m after consideration of the air supply and ventilation systems in construction. The building incorporated a wall column structure with a core wall of reinforced concrete, and the strength of the concrete varied according to the zoning per floor. The strength of the core wall was 50 MPa from the first to 45th floors and 30 MPa from the 46th to the 60th floors. The strength of the structures was 40 MPa from the first to the 45th floors and 30 MPa from the 46th to the 60th floors. The specifications of the super high-rise standard apartment houses considered in this study are summarized in Table 2.

3. Main construction materials

3.1. Overview

Based on other research that analyzes the specifications of construction for an apartment house built in May 2004, the CO_2 emissions were evaluated per construction process for the purpose of selecting the main construction materials that emit CO_2. As a result, the amount of CO_2 emission by the production of construction materials per process was highest in the process of building work (352.36 kg-CO_2/m^2), followed by the processes of facility work (49.68 kg-CO_2/m^2) and earth work (11.15 kg-CO_2/m^2). The amount of CO_2 emission during building work was found to constitute about 85% of all emissions during the construction procedure. Table 3 shows the unit CO_2 emission and its percentage per construction process [14].

This study was limited to the process of building work because it was impossible to compare construction processes under identical conditions. The process of facility work varies according



(a) 36 m^2 four-unit combination Tower Type

(b) 46 m^2 four-unit combination Tower Type

(c) 84 m^2 four-unit combination Tower Type

(d) 125 m^2 four-unit combination Tower Type

Fig. 2. Block arrangements and combinations of living units of general standard apartment houses.

Table 2
Constitution of super high-rise standard apartment houses.

Constitution	Description	
Lettable area	118.00 m^2, 121.00 m^2, 178.00 m^2	
Block arrangement	Tower type: the ratio of the short side to the long side on a plan is 1:4 or less.	
Combination of living units	Tower type: 1 combination (single combination)	
Height of floor	2.9 m: air supply and ventilation systems are taken into account.	
Number of floors	60-story building	
Structure	Wall column structure of reinforced concrete	
Concrete strength	Structure	1st to 45th: 40 MPa 46th to 60th: 36 MPa
	Core	1st to 45th: 50 MPa 46th to 60th: 40 MPa

to the type and dimensions of a facility and the scope of the energy saving plan, while earth work also varies depending on work type and soil quality. Also, floors below ground level were excluded, because it was impossible to establish the same criteria for size and purpose for these floors [15].

Table 3
Unit CO_2 emissions and percentage per construction process.

Process	Unit CO_2 emission (unit: kg-CO_2/m^2)	Percentage (%)
Building work	352.36	85.3
Facility work	49.68	12.0
Earth work	11.15	2.7
Total	413.19	100.0

3.2. Selection of main construction materials

Most of the current environmental load evaluation programs for buildings are operated by simply entering data on the specifications of material quantities after the detail design stage of a building. This method has shortcomings that are difficult to evaluate for an environmental load evaluation at the basic design stage, and significant time and effort are required to input all of the construction materials used.

To remedy such problems, those construction materials having considerable effects on the occurrence of environmental load, i.e., main materials, should be selected first.

In this study, the construction materials significantly contributing to CO_2 emissions were selected according to the unit CO_2 emissions. These emission levels were determined by an inter-industry analysis on the development of technologies to reduce CO_2 emission based on the construction and material quantities for an apartment building. As for the process of building work, six main materials were selected for the general standard apartment houses: iron rods, REMICON (ready mixed concrete), plywood, concrete products, industrial plastic products, and paints. Seven main materials were selected for the super high-rise standard apartment house: iron rods, REMICON, plywood, concrete products, industrial plastic products, paints, and aluminum products. The ratios of CO_2 emission per material group are explained in Table 4.

4. Estimation of main construction material quantities and establishment of a unit materials database for standard apartment house

4.1. Estimation of quantities of main construction materials

To estimate the quantities of the main construction materials for the general standard apartment houses, the scope of estimation was limited to the six groups of main materials, with

a) 118 m^2 four-unit combination
121 m^2 two-unit combination

b) 178 m^2 four-unit combination

Fig. 3. Block arrangement and combination of living units of super high-rise standard apartment house.

Table 4
Ratios of CO_2 emission per main material group.

Main material group	Amount of CO_2 emission
Iron rods	42.37%
REMICON (ready mixed concrete)	23.72%
Plywood	4.03%
Concrete products	3.47%
Industrial plastic products	3.37%
Paints	3.13%
Aluminum products	6.17%
Total	86.26%

90 variables of estimation according to the combinations of five areas, three types of block arrangement, and six floors. For the super high-rise standard apartment house, the scope was limited to the seven groups of main materials for a 60-story building with a single type of block arrangement composed of three areas. Table 5 shows the scopes of quantity estimation per standard apartment house. Of the estimated main construction materials, the difference between the general and the super high-rise standard apartment houses is whether aluminum products were used in the doors and windows.

When the main material quantities were estimated per group, the main materials were selected, and then the itemized unit costs provided in the Standard Estimating System of the construction work were applied to the selected materials so that other sub-materials were all estimated. The number of the estimated materials is 71.

Therefore, it was possible to determine the scope of estimation by selecting a combination of area, block arrangement, combination of living units, number of floors, and other alternative elements. Subsequently, a database was established for the estimation of quantities to be carried out automatically according to the decided scope. Tables 6 and 7 show the specifications of the estimated quantities per main material and of the estimated quantities by the itemized unit costs for the general standard apartment houses. Tables 8 and 9 shows these specifications of calculated material quantities and on calculated basic unit for the super high-rise standard apartment house.

4.2. Establishment of a database for the basic units of main materials

The methods to analyze basic units of construction materials are divided largely into an individual integration method, including inter-industry analysis and a mixed analysis. The individual integration method is an attempt to identify and integrate the environmental loads during such stages of a building life cycle as collection, transportation, and processing of construction materials and energy. Inter-industry analysis is a method by which an analysis is made through direct/indirect relations in the flows of construction materials and energies, based on the circulation data of construction materials and the energies used during the life cycle of a building. The inter-industry analysis is provided in the Input–Output Table by the Bank of Korea. The mixed analysis is a combination of the individual integration method and the inter-industry analysis so as to compensate for the weak points of each method [16–18].

As shown in Table 10, a database on the basic units of the main materials was established by mixed analysis including 94 construction materials classified by a national LCI database according to the individual integration method and basic units

Table 5
Scope of quantity estimation per standard apartment house.

	Item	Variables of quantity estimation			
		General standard apartment house		Super high-rise standard apartment house	
		Type	Condition	Type	Condition
Conditions of building construction	Area	5 types	5 × 3 × 6 = 90	3 types	1
	Block arrangement	3 types		1 type	
	Number of floors	6 types		1 building	
Estimated materials		6 groups		7 groups	

Table 6
Specifications of quantity estimation for general standard apartment houses.

No.	Article	Standard	Unit	36 m²		
				2-Unit Flat Type	4-Unit Flat Type	4-Unit Tower Type
1	REMICON	25-240-15	m^3	518.83	1,037.66	1,068.79
		25-210-15	m^3	1,426.66	2,853.32	2,938.92
	Sub-Total		m^3	1,945.49	3,890.98	4,007.71
2	Deformed iron bar	H10	TON	159.74	319.48	329.07
		H13	TON	82.93	165.87	170.84
		H16	TON	30.64	61.28	63.12
		H19	TON	30.23	60.46	62.28
		H22	TON	93.15	186.30	191.88
		H25	TON	11.44	22.88	23.56
	Sub-Total		TON	408.14	816.27	840.76
3	Plywood mould	3 times (Lumber)	m^2	6,089.25	12,178.50	12,543.85
	Plywood mould	Wall (Euro form)	m^2	10,797.23	21,594.46	22,242.30
	Sub-Total		m^2	16,886.48	33,772.96	34,786.15
	Gang form	Elev./Pit	m^2	719.82	1,439.63	1,482.82
	Gang form	Ribbed side wall	m^2	622.54	1,245.09	1,282.44
	Sub-Total		m^2	1,342.36	2,684.72	2,765.26
4	Plain concrete		m^3	20.67	41.33	41.33
	Cement brick	0.5B	m^2	825.89	1,546.88	1,651.79
	Cement brick	1.0B	m^2	-	-	-
	Cement		BAG	2,047.60	4,197.36	4,142.72
	Sand		m^3	156.54	315.82	317.98
5	Industrial Plastic Product	T59	m^2	692.87	1,291.77	1,385.73
	Laminated paper board	T79	m^2	546.19	546.19	1,092.37
	Insulator preventing condensation	T9	m^2	253.94	402.44	507.87
	Vinyl floor paper		m^2	231.79	463.58	463.58
	PVC ceiling panel	Ceiling of the bathroom	m^2	104.10	208.20	208.20
	PVC rain leader pipe	Φ150	m	218.00	348.00	348.00
6	Water-based paint	Inside wall, 3 times	m^2	3,175.75	6,507.98	7,701.19
	Water-based paint	Inside ceiling, 3 times	m^2	182.10	687.19	687.19
	Sub-Total		m^2	3,357.85	7,195.17	8,388.38
	Ceramin paint	3 times	m^2	48.42	138.15	138.15
	Anti-corrosive paint		m^2	247.00	643.00	643.00
	Pattern coat		m^2	922.02	1,400.88	1,400.88
	Multi-color paint	3 times	m^2	328.20	519.60	519.60

Table 7
Specifications of estimation by itemized unit cost for general standard apartment houses.

No.	Article	Standard	Unit	Quantity	36 m²		
					2-Unit flat type	4-Unit flat type	4-Unit tower type
3	Plywood mould	3 times (lumber)	m^2		6,089.25	12,178.50	12,543.85
	Waterproof plywood	1st grade, 12 × 1220 × 2440 mm (m^2)	m^2	0.3656	2,226.23	4,452.46	4,586.03
	Rectangular lumber	Radiata pine (m^3)	m^3	0.0134	81.60	163.19	168.09
	Wire	Annealing, 4.0 mm	kg	0.1336	813.52	1,627.05	1,675.86
	Nail	Common type, N 75	kg	0.0922	561.43	1,122.86	1,156.54
	Stripper	For wood (water-based)	ℓ	0.0875	532.81	1,065.62	1,097.59
	Plywood mould	Wall (Euro form)	m^2		10,797.23	21,594.46	22,242.30
	Metal form (Euro form)	600 × 1200 × 63.5 mm	Sheet	0.0710	766.60	1,533.21	1,579.20
	Metal form (Euro form)	Inside wall corner panel (200 + 200) 1200	Sheet	0.0020	21.59	43.19	44.48
	Steel accessory of mould	Wedge pin, 90 mm	Q'ty	1.9002	20,516.90	41,033.80	42,264.81
	Steel accessory of mould	Flat tie, L = 200 mm	Q'ty	2.0026	21,622.53	43,245.07	44,542.42
	Steel pipe scaffolding	Scaffolding pipe, 48.6 × 2.3 mm	m	0.0773	834.63	1,669.25	1,719.33
	Steel accessory of mould	Whale hook, steel level (large)	Q'ty	0.2827	3,052.38	6,104.75	6,287.90
	Stripper	For wood (water-based)	ℓ	0.0125	134.97	269.93	278.03
	Gang form	ELEV./PIT	m^2		719.82	1,439.63	1,482.82
	Gang form	Ribbed side wall	m^2		622.54	1,245.09	1,282.44
	Sub-total				1,342.36	2,684.72	2,765.26
5	Laminated paper board	T59	m^2		692.87	1,291.77	1,385.73
	Foamed polystyrene board	Specific gravity, 0.03, 50 mm	m^2	1.1000	762.15	1,420.95	1,524.31
	Vinyl acetate adhesive	Polystyrene, rock wool	kg	0.3000	207.86	387.53	415.72
	Laminated paper board	T79	m^2		546.19	546.19	1,092.37
	Foamed polystyrene board	Specific gravity, 0.03, 70 mm	m^2	1.1000	600.80	600.80	1,201.61
	Vinyl acetate adhesive	Polystyrene, rock wool	kg	0.3000	163.86	163.86	327.71
	Insulator preventing condensation	T9	m^2		253.94	402.44	507.87
	Extruded foamed polystyrene board	Extrusion, specific gravity, 0.03, 9 mm	m^2	1.1000	279.33	442.68	558.66
	Nail	Common type, N 50	kg	0.0300	7.62	12.07	15.24
	Vinyl floor paper		m^2		231.79	463.58	463.58
	Vinyl sheet	Monorium, 1.8 mm	m^2	1.0500	243.38	486.76	486.76
	Vinyl acetate adhesive	For vinyl tiles	kg	0.4000	92.72	185.43	185.43

Table 8
Specifications of calculated material quantities for super high-rise standard apartment houses.

No.	Article	Standard	Unit	Quantity
1	REMICON	25-500-21	m^3	12,050.00
		25-400-21	m^3	17,036.00
		25-300-15	m^3	4,571.00
2	Deformed iron bar	HD10, payment on delivery	Ton	33.83
		HD13, payment on delivery	Ton	2,218.44
		HD16, payment on delivery	Ton	1,180.00
		HD19, payment on delivery	Ton	505.13
		HD22, payment on delivery	Ton	104.10
		HD25, payment on delivery	Ton	306.38
		HD32, payment on delivery	Ton	594.73
		HD35, payment on delivery	Ton	266.81
		SHD32 (500 kg), payment on delivery	Ton	781.88
	Deformed iron bar (DOWEL BAR)	D13, payment on delivery	Ton	108.72
		D16, payment on delivery	Ton	53.71
		Sub-total	Ton	6,153.74
3	Mould/3 times	Main operating part/(beam, etc.)	m^2	2,803.00
	Mould/curb stone, equipment foundation		m^2	174.00
	Perimeter area of main operating part, SLAB mould	SKY-DECK or higher level (1F∼60F)	m^2	56,798.00
	Core of main operating part, SLAB mould	SKY-DECK or higher level (1F∼60F)	m^2	4,290.00
		Sub-total	m^2	64,065.00
	Mould/APT retaining wall	Floors above ground, machine room, pit	m^2	2,122.00
	Core wall of main operating part, mould/ B5∼rooftop house	ACS + gang form	m^2	22,151.00
	Perimeter area of main operating part, outside mould/above ground	ACS + gang form	m^2	8,024.00
	SET-BACK part, outside mould	RAIL + gang form	m^2	798.00
		Sub-total	m^2	30,973.00
	Mould/APT column	AL-form/inside	m^2	13,647.00
	Mould/APT retaining wall	AL-form/inside	m^2	22,794.00
	Mould/inside wall of APT balcony	AL-form/inside	m^2	2,639.00
		Sub-total	m^2	39,080.00
	Mould/outside retaining wall of rooftop floor	Steel form	m^2	819.00
	Mould/inside retaining wall of rooftop floor	Euro form	m^2	2,730.00
	Mould/stairs	Slab + riser	m^2	3,288.00
4	Application of plain concrete	25-180-15	m^3	224.00
	Cement brick	0.5B	m^2	2,495.00
	Cement brick	1.0B	m^2	75,359.00
	Cement	40 kg, payment on delivery	Bag	28,088.00
	Sand		m^3	1,072.00
5	Iso Pink	T: 10 mm, 0.03, special size	m^2	3,543.00
	Installation of ceiling insulator	10 mm, W = 450 (Iso Pink)	m^2	2,694.00
	Installation of ceiling insulator/piloti	10T, Iso Pink	m^2	681.00
		Sub-total		6,918.00
	Iso Pink	T: 30 mm, 0.03, special size	m^2	768.00
	Installation of ceiling insulator/attic	30T, Iso Pink	m^2	732.00
		Sub-total		1,500.00
	Iso Pink	T: 40 mm, 0.03, special size	m^2	216.00
	Installation of ceiling insulator/piloti	40T, Iso Pink	m^2	206.00
		Sub-total		422.00
	Iso Pink	T: 50 mm, 0.03, special size	m^2	2,629.00
	Installation of ceiling insulator	50T, Iso Pink	m^2	2,503.00
		Sub-total		5,132.00
	Iso Pink	T: 70 mm, 0.03, special size	m^2	753.00
	Installation of ceiling insulator/rooftop floor	70T, Iso Pink	m^2	717.00
		Sub-total		1,470.00
	Installation of sound isolation material/ air-conditioning room, mid-machine room	Floor, 50 mm (material + labor)	m^2	112.00
	Installation of sound isolation material/ air-conditioning room, mid-machine room	Floor, 2 5mm (material + labor)	m^2	1,376.00
		Sub-total		1,488.00
	Vinyl asbestos-free tile	3 × 300 × 300 (material cost)	m^2	207.00
	Designated floor material (incombustible)	Floor, 3 mm	m^2	7,214.00
	Rain leader pipe/balcony	∅100	m	2,373.00
6	Water-based paint	Inside wall, 3 times	m^2	4,630.00
	Water-based paint	Inside wall, 3 times/G.B side	m^2	4,283.00
	Water-based paint	Inside ceiling, 3 times	m^2	1,456.00
	Water-based paint	Inside ceiling/G.B side	m^2	897.00
		Sub-total	m^2	11,266.00
	Designated paint (incombustible)	Inside wall	m^2	6,899.00
	Designated paint (incombustible)	Inside wall/G.B side	m^2	2,138.00
	Designated paint (incombustible)	Inside ceiling	m^2	2,322.00
	Designated paint (incombustible)	Inside ceiling/G.B side	m^2	262.00
	Designated paint (incombustible)	Base	m^2	291.00
		Sub-total	m^2	11,912.00
	Insulating paint	Inside wall G.B side, Benjamin N.DOVE06	m^2	13,274.00
	Insulating paint	Ceiling G.B side, Benjamin N.DOVE06	m^2	6,812.00

Table 8 (*Continued*)

No.	Article	Standard	Unit	Quantity
		Sub-total	m^2	20,086.00
	Vinyl paint	Wall G.B side, Benjamin N.DOVE06	m^2	120.00
	Vinyl paint	Ceiling G.B side, Benjamin N.DOVE06	m^2	2,892.00
		Sub-total	m^2	3,012.00
	Silicon paint	Outside wall	m^2	6,694.00
	Acrylic paint	Base	m^2	72.00
	Anti-corrosive paint	Steel area, 1 time	m^2	4,602.00
	Ready-mixed paint	Steel area, 2 times	m^2	4,602.00
7	AL ceiling material/F 1 piloti	600 × 600	m^2	139.00
	AL spandrel	W = 200	m^2	272.00
	AL sheet folding/F 1 piloti	1.5T + frame included	m^2	72.00
	AL sheet folding/F 1 piloti	1.5T + frame included/corrugated	m^2	43.00
	AL sheet folding/rooftop, upper area of F1 balcony	3T, insulation + baking type fluoric paint	m^2	23.00
	AL molding installation	Color	m	2,354.00
	AL molding installation (wall)/balcony	20 × 30	m	7,662.00
	AL sheet flashing/outside of higher floors	¬500 × 80, W = 630	m	34.00
	AL sheet flashing/outside parapet	260 × 140, W = 620	m	84.00
	AL sheet parapet cap installation/roof garden	310 × 180, W = 780	m	14.00
	Parapet cap installation/rooftop floor	1,360 × 160, W = 1,680	m	74.00
	AL grille (curtain wall area)	For windows	m^2	61.00

Table 9
Specifications on calculated basic units for super high-rise standard apartment houses.

No.	Article	Standard	Unit	Basic Unit	Quantity
3	Mould/3 times	Main operating part/(beam, etc.)	m^2		2,803.00
	Waterproof plywood	1st grade, 12 × 1,220 × 2,440 mm (m^2)	m^2	0.3656	1,024.78
	Rectangular lumber	Radiata pine (m^3)	m^3	0.0134	37.56
	Wire	Annealing, 4.0 mm	kg	0.1336	374.48
	Nail	Common type, N 75	kg	0.0922	258.44
	Stripper	For wood (water-based)	ℓ	0.0875	245.26
	Mould/curb stone, equipment foundation		m^2		174.00
	Waterproof plywood	1st grade, 12 × 1,220 × 2,440 mm (m^2)	m^2	0.3656	63.61
	Rectangular lumber	Radiata pine (m^3)	m^3	0.0134	2.33
	Wire	Annealing, 4.0 mm	kg	0.1336	23.25
	Nail	Common type, N 75	kg	0.0922	16.04
	Stripper	For wood (water-based)	ℓ	0.0875	15.23
	Perimeter area of main operating part, SLAB mould	SKY-DECK or higher level (1F∼60F)	m^2		56,798.00
	Waterproof plywood	1^{st} grade, 12 × 1,220 × 2,440 mm (m^2)	m^2	0.3656	20,765.35
	Rectangular lumber	Radiata pine (m^3)	m^3	0.0134	761.09
	Wire	Annealing, 4.0 mm	kg	0.1336	7,588.21
	Nail	Common type, N 75	kg	0.0922	5,236.78
	Stripper	For wood (water-based)	ℓ	0.0875	4,969.83
	Core of main operating part, SLAB mould	SKY-DECK or higher level (1F∼60F)	m^2		4,290.00
	Waterproof plywood	1^{st} grade, 12 × 1,220 × 2,440 mm (m^2)	m^2	0.3656	1,568.42
	Rectangular lumber	Radiata pine (m^3)	m^3	0.0134	57.49
	Wire	Annealing, 4.0 mm	kg	0.1336	573.14
	Nail	Common type, N 75	kg	0.0922	395.54
	Stripper	For wood (water-based)	ℓ	0.0875	375.38
	Mould/APT retaining wall	Floors above ground, machine room, pit	m^2		2,122.00
	Metal form (Euro form)	600 × 1,200 × 63.5 mm	Sheet	0.0710	150.66
	Metal form (Euro form)	Inside wall corner panel (200 + 200) 1,200	Sheet	0.0020	4.24
	Steel accessory of mould	Wedge pin, 90 mm	Q'ty	1.9002	4,032.22
	Steel accessory of mould	Flat tie, L = 200 mm	Q'ty	2.0026	4,249.52
	Steel pipe scaffolding	Scaffolding pipe, 48.6 × 2.3 mm	m	0.0773	164.03
	Steel accessory of mould	Whale hook, steel level (large)	q'ty	0.2827	599.89
	Stripper	For wood (water-based)	ℓ	0.0125	26.53
	Core wall of main operating part, mould/B5∼rooftop house	ACS + gang form	m^2		22,151.00
	Perimeter area of main operating part, outside mould/above ground	ACS + gang form	m^2		8,024.00
	SET-BACK part, outside mould	RAIL + gang form	m^2		798.00
	Sub-total	M^2		30,973.00	
	Mould/APT column	AL-form/inside	m^2		13,647.00
	Mould/APT retaining wall	AL-form/inside	m^2		22,794.00
	Mould/inside wall of APT balcony	AL-form/inside	m^2		2,639.00
	Sub-total	M^2		39,080.00	
	Mould/outside retaining wall of rooftop floor	Steel form	m^2		819.00
	Mould/inside retaining wall of rooftop floor	Euro form	m^2		2,730.00
	Mould/stairs	Slab + riser	m^2		3,288.00
5	Iso Pink	T: 10 mm, 0.03, special size	m^2		3,543.00
	Iso Pink	10 mm, 0.03	m^2	1.1000	3,897.30
	Nail	N25	kg	0.0300	106.29
	Installation of ceiling insulator	10 mm, W = 450 (Iso Pink)	m^2		2,694.00
	Iso Pink	10 mm, 0.03	m^2	1.1000	2,963.40
	Nail	N25	kg	0.0300	80.82
	Installation of ceiling insulator/piloti	10T, Iso Pink	m^2		681.00

Table 9 (*Continued*)

No.	Article	Standard	Unit	Basic Unit	Quantity
	Iso Pink	10 mm, 0.03	m^2	1.1000	749.10
	Nail	N25	kg	0.0300	20.43
	Iso Pink	T: 30 mm, 0.03, special size	m^2		768.00
	Iso Pink	30 mm, 0.03	m^2	1.1000	844.80
	Nail	N 50	kg	0.0300	23.04
	Installation of ceiling insulator/attic	30T, Iso Pink	m^2		732.00
	Iso Pink	30 mm, 0.03	m^2	1.1000	805.20
	Nail	N 50	kg	0.0300	21.96
	Iso Pink	T: 40 mm, 0.03, special size	m^2		216.00
	Iso Pink	40 mm, 0.03	m^2	1.1000	237.60
	Nail	N 65	kg	0.0300	6.48
	Installation of ceiling insulator/piloti	40T, Iso Pink	m^2		206.00
	Iso Pink	40 mm, 0.03	m^2	1.1000	226.60
	Nail	N 65	kg	0.0300	6.18
	Iso Pink	T: 50 mm, 0.03, special size	m^2		2,629.00
	Iso Pink	50 mm, 0.03	m^2	1.1000	2,891.90
	Nail	N 65	kg	0.0300	78.87
	Installation of ceiling insulator	50T, Iso Pink	m^2		2,503.00
	Iso Pink	50 mm, 0.03	m^2	1.1000	2,753.30
	Nail	N 65	kg	0.0300	75.09
	Iso Pink	T:70 mm, 0.03, special size	m^2		753.00
	Iso Pink	70 mm, 0.03	m^2	1.1000	828.30
	Nail	N 100	kg	0.0300	22.59
	Installation of ceiling insulator/rooftop floor	70T, Iso Pink	m^2		717.00
	Iso Pink	70 mm, 0.03	m^2	1.1000	788.70
	Nail	N 100	kg	0.0300	21.51
	Installation of sound isolation material/ air-conditioning room, mid-machine room	Floor, 50 mm (material + labor)	m^2		112.00
	Installation of sound isolation material/ air-conditioning room, mid-machine room	Floor, 25 mm (material + labor)	m^2		1,376.00
	Sub-total			1,488.00	
	Vinyl asbestos-free tile	3 × 300 × 300 (material cost)	m^2		207.00
	Vinyl sheet	Monorium, 1.8 mm	m^2	1.0500	217.35
	Vinyl acetate adhesive	For vinyl tiles	kg	0.4000	82.80
	Designated floor material (incombustible)	Floor, 3 mm	m^2		7,214.00
	Designated floor material (incombustible)	Floor, 3 mm	m^2	1.0500	7,574.70
	Adhesive (for AS tiles)		kg	0.2400	1,731.36
	Wax		ℓ	0.1200	865.68

Table 10
Database of the basic units of main materials.

No	Article	Korea Institute of Construction Technology		Korea Environmental Industry Technology Institute		Inter-Industry Analysis (Domestic)		Inter-Industry Analysis (Domestic & Overseas)	
		Amount of CO_2 Emission	Unit	Amount of CO_2 Emission	Unit	Amount of CO_2 Emission	Unit	Amount of CO_2 Emission	Unit
1	Steel equal angles	0.395	CO_2-kg/kg			2.026	CO_2-kg/kg	5.186	CO_2-kg/kg
2	Steel channels	0.395	CO_2-kg/kg						
3	Steel I beams	0.394	CO_2-kg/kg						
4	Steel H beams	0.388	CO_2-kg/kg						
5	General deformed iron bar	0.386	CO_2-kg/kg			1.646	CO_2-kg/kg	4.417	CO_2-kg/kg
6	High-tension deformed iron bar	0.396	CO_2-kg/kg						
7	Sand (General)	3.576	CO_2-kg/m^3			5.332	CO_2-kg/m^3	8.920	CO_2-kg/m^3
8	River sand	1.590	CO_2-kg/m^3						
9	Sea sand	2.097	CO_2-kg/m^3						
10	Ground sand	0.254	CO_2-kg/m^3						
11	Forest sand	5.016	CO_2-kg/m^3						
12	Gravel	11.146	CO_2-kg/m^3			5.157	CO_2-kg/m^3	8.627	CO_2-kg/m^3
13	REMICON transport (8-ton dump truck)	1.091	CO_2-kg/m^3*km						
14	REMICON transport (10.5-ton dump truck)	1.234	CO_2-kg/m^3*km						
15	REMICON transport (15-ton dump truck)	1.005	CO_2-kg/m^3*km						
16	REMICON transport (Concrete mixer truck)	0.660	CO_2-kg/m^3*km						
17	Shaped steel works	29,842.766	CO_2-kg/10 m^3						
18	REMICON works	186.678	CO_2-kg/m^2						
19	PVC wall paper	1.188	CO_2-kg/m^2			24.367	CO_2-kg/kg	42.323	CO_2-kg/kg
20	Concrete brick	0.122	CO_2-kg/kg			0.189	CO_2-kg/each	0.353	CO_2-kg/each
70	Paint, Unsaturated polyester type			2,719.600	CO_2-kg/ton				
71	Paint, Water-soluble emulsion type			308.930	CO_2-kg/ton				
72	Paint, Water-soluble water type			1,066.900	CO_2-kg/ton				

Table 10 (*Continued*)

No	Article	Korea Institute of Construction Technology		Korea Environmental Industry Technology Institute		Inter-Industry Analysis (Domestic)		Inter-Industry Analysis (Domestic & Overseas)	
		Amount of CO_2 Emission	Unit	Amount of CO_2 Emission	Unit	Amount of CO_2 Emission	Unit	Amount of CO_2 Emission	Unit
73	Paint, Amino-alkyd type			783.340	CO_2-kg/ton				
74	Paint, Acrylic type			873.730	CO_2-kg/ton	11.445	CO_2-kg/kg	47.987	CO_2-kg/kg
75	Paint, Alkydenamel type			221.350	CO_2-kg/ton				
76	Paint, Epoxy type			3,157.900	CO_2-kg/ton	11.770	CO_2-kg/kg	49.348	CO_2-kg/kg
77	Paint, Urethane type			366,220.000	CO_2-kg/ton	9.393	CO_2-kg/kg	39.383	CO_2-kg/kg
78	REMICON, 25-210-12			400.132	CO_2-kg/m^3	171.504	CO_2-kg/m^3	321.088	CO_2-kg/m^3
79	REMICON, 25-210-15			409.981	CO_2-kg/m^3				
80	REMICON, 25-240-12			406.087	CO_2-kg/m^3				
81	REMICON, 25-240-15			419.572	CO_2-kg/m^3				
82	Gypsum board			135.015	CO_2-kg/kg				
83	Cement			1,048.800	CO_2-kg/ton	0.497	CO_2-kg/kg	0.980	CO_2-kg/kg
84	Glass wool			157.033	CO_2-kg/kg				
85	Sheet glass			750.830	CO_2-kg/ton				
86	Glass wool board			128.473	CO_2-kg/kg				
87	Glass wool pipe cover			147.178	CO_2-kg/kg				

Table 11
Overview of the constructions of the existing and general standard apartment houses.

Item	Overview of construction	
	Existing apartment house	General standard apartment house
Lettable area	85.65 m^2	84 m^2
Number of floors	20	20
Height of a floor	2.9 m	2.9 m
Number of households	40	40
Combination of living units	2-unit combined flat type	2-unit combined flat type
Structure	Reinforced concrete	Reinforced concrete

of materials according to the inter-city analysis on the basis of the Input–Output Table for the year 2003 [19].

Using the established database on the basic units of the main materials according to the mixed analysis, data can be input into the basic design stage according to a selected combination of area, block arrangement, combination of living units, number of floors, and other alternative elements. Through an automatic estimation of quantities, the amount of CO_2 emitted by the main materials to be used for a construction project can be calculated as shown in the following Eq. (1):

$$\text{The amount of } CO_2 \text{ emission by the main materials} = \sum (\text{Quantity of a main material} \times \text{Basic unit of } CO_2) \quad (1)$$

5. A case of environmental load evaluation

5.1. Overview

The construction conditions of a general standard apartment house were based on those of an existing apartment house built in May 2004. For the existing apartment house, the environmental load (CO_2) was calculated with the Input–Output Table (2003, Domestic and Overseas) using the data from the total volume of the materials used in the construction work. Also, the environmental load for the general standard apartment house was calculated with the Input–Output Table used in estimating the environmental load for the existing apartment house using main material quantities, which were drawn from the method presented by this study. Then, the results of environmental load were comparatively analyzed [20].

5.2. Conditions of environmental load evaluation

The existing apartment house was a 20-story building with 40 households, the areas of which were 85.65 m^2. The general standard apartment house in this study was designed to have the same conditions of evaluation as a 20-story building with 40 households, each with an area of 84.0 m^2. The constructions of the existing and general standard apartment houses are summarized in Table 11.

5.3. Method of environmental load evaluation

The environmental load for the existing apartment house was evaluated based on the specifications of material quantities made after construction according to the Input–Output Table, and that of the general standard apartment house was evaluated through an automatic estimation of quantities of the main materials according to the mixed analysis. The former method and the method suggested by this study are compared in Table 12.

5.4. Results of environmental load evaluation

As a result of the environmental load evaluation, the load for the general standard apartment house suggested by this study was evaluated to be 1554.00 ton-CO_2, about 77.5% (2005.75 ton-CO_2) of

Table 12
Comparison of the methods used to evaluate apartment houses.

Item	Former method	Method suggested by the study
Stage of evaluation	After construction	Stage of basic design
Quantity of material	Actual amounts of the materials used	Direct calculation of the materials
How to input	Direct entering of data of material quantities	Automatic calculation of quantities of materials
Method of evaluation	Inter-industry analysis	Mixed analysis

Table 13
Results of environmental load evaluation.

Evaluation item	Existing apartment house (ton-CO_2)	Standard apartment house (ton-CO_2)
Amount of environmental load	2005.75	1554.00
Ratio of environmental load	100%	77.48%

that calculated with the material data used in building the existing apartment house. To estimate the amount of CO_2 emitted by the construction materials for the suggested general standard apartment house, this study chose a method for selecting main construction materials that emit about 80% of the CO_2 emitted from the production of materials used for building an apartment house.

Therefore, it is thought that the method in this study is useful to evaluate environmental load for the process of producing construction materials by selecting main materials for the suggested standard apartment house. Because the result of our method is close to the initial target, 80% of the CO_2 emission from the materials used in a general apartment house, it will be possible to estimate the total amount of CO_2 emissions based on the construction materials used in the building of an apartment house. Table 13 shows the results of environmental load evaluation.

6. Conclusions

This study aimed to develop a technique for evaluating the environmental load (CO_2) of an apartment house with data available in the planning and basic design stages. The results of the study are as follows:

1. The models of a general standard apartment house and of a super high-rise standard apartment house were selected based on the five floor plans designated by the Green Home evaluation reference houses of the government.
2. Main construction materials contributing to more than about 80% of the CO_2 emission in building work were selected, and the quantities of the main materials were calculated according to the type of apartment houses. Using the quantity data, a database was established to evaluate environmental load.
3. The environmental load from the production of construction materials in the building of the general standard apartment house suggested by this study was evaluated to be 1554.00 Ton-CO_2, about 77.5% of that emitted from an existing apartment house and close to the initial target of 80%.
4. Therefore, it is believed that the proposed method will be allow the evaluation, at the stages of architectural planning and basic design, of the amount of CO_2 to be emitted by the production of construction materials in a building project using such data as area, block arrangement, combination of living units, and number of floors.
5. In addition, the results of this study are considered to be useful as basic data for developing, in the stage of basic design, a program to evaluate the environmental load for the entire life of a building, without using any data obtained during the construction stage.

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